Goath

GENERAL ELECTRIC

TECHNICAL INFORMATION SERIES

Title Page

DEPARTMENT OF DEFENSE
PLASTICS TECHNICAL EVALUATION CENTER
PICATINNY ARSENAL, DOVER, N. J.

AUTHOR	SUBJECT CLASSIFICATION	NO.
M. G. Noble	Wire and Cable Insulation	R-58-ChSD-701
		DATE 10/1/58

TITLE
Comparison of Silicone Rubber and Teflon as Extruded Insulation for Electrical Conductors

ABSTRACT
Silicone rubber and Teflon as wire insulation are compared in cost, raw material properties, installation and handling behavior, service and electrical characteristics, and chemical resistance.

G.E. CLASS	REPRODUCIBLE COPY FILED AT	NO. PAGES
I	Waterford, New York	11
GOV. CLASS. -		

CONCLUSIONS
Each of the materials has areas of relative superiority; in other areas equivalent properties are demonstrated. Among more important points are:

1. Service temperature ranges are equivalent.
2. Solderability of both is excellent.
3. Cost and specific gravity of Teflon are higher.
4. Installation characteristics and cold flow resistance of silicone are better.
5. Teflon is outstanding electrically; however, silicone has areas of superiority.
6. In general chemical resistance Teflon ranks higher, but in ozone and radiation resistance silicone is superior.

The design engineer must decide which areas are most significant in each application.

By cutting out this rectangle and folding on the center line, the above information can be fitted into a standard card file.

2/12

INFORMATION PREPARED FOR Design engineers specifying wire insulation

TESTS MADE BY M. G. Noble

COUNTERSIGNED R/Daily DIV. Rubber Market Development

DIVISIONS Silicone Products Dept. LOCATION Waterford, New York

FN-610-1 (1-49) new

INTRODUCTION

Silicone rubber and Teflon* are among the materials most commonly used for wire and cable insulation designed for service at high temperatures or under other severe conditions which degrade the electrical or physical properties of other materials. The number of such applications is increasing steadily.

Because of their mutual superiority to other materials in such applications, comparisons between silicone rubber and Teflon are inevitable. However, the subject is complex and a great many factors must be taken into consideration before arriving at a conclusion. This report has been prepared to assist design engineers in selecting the most suitable wire insulation for specific applications. The salient points of comparison in composition, cost and performance are presented in tabular form for easy reference. These comparisons are discussed in detail in the text which follows. The outline form of the tables has been repeated in the text to expedite referral.

The information included in this report was obtained from the materials suppliers' literature, wire and cable manufacturers and users, testing laboratories, Government specifications and other sources.

* Registered Trade-Mark, E. I. duPont de Nemours & Company

COMPARISON OF PROPERTIES

Silicone Rubber and Teflon for Wire Insulation

	Silicone Rubber	Teflon
I. Raw Material Properties		
Chemical Composition	Silicon, oxygen carbon, hydrogen (plus mineral fillers)	Carbon, Fluorine
Classification	Thermosetting	Thermoplastic
Specific Gravity	1.2 (typical)	2.1
Price per Pound	$3.25 (typical)	$7.40 (typical)
Price per Pound-Volume*	$3.90 (typical)	$15.50 (typical)
II. Insulated Wire Properties		
A. Installation and Handling		
1. Lengths supplied	Continuous - uniform quality	Frequently supplied in short lengths
2. Ease of stripping	Very easy - minimizes danger of damaging conductor	More difficult - greater danger of damaging conductor
3. Effect of right angle bends	None	Crack propagation rate very high
4. Crushing with pliers	Can be damaged	Can be damaged
5. Flexibility		
(a) Room Temperature	Excellent	Fair
(b) Retention at low temperature	Excellent	Good
6. Solderability	Excellent	Excellent
7. Space factors	Very good (.012-.015" insulation walls)	Excellent (.008" insulation walls)
8. Conductor plating	Bare copper Lead-tin alloy Silver plate Nickel plate	Silver plate Nickel plate

* Price per pound times specific gravity - a measure of volume cost.

	Silicone Rubber	Teflon
II. Insulated Wire Properties (Cont'd)		
B. Service Characteristics		
1. Service temperature range	Below -100°F to +500°F	Below -100°F to +500°F
(a) High temperature stability	Excellent	Excellent
(b) Low temperature flex	Excellent	Good
2. Overload reliability	Withstands 300-400% overloads	Decomposes under 300-400% overloads
3. Flame resistance	Slow burning, forms non-conducting ash	Nonflammable, but decomposes in direct flame, releasing toxic fumes, melting, and exposing conductor.
4. Cold flow resistance	Very good	Poor
5. Cut-through resistance		
(a) Thumb nail	Poor-good	Very good
(b) Laced into harness	New compounds good	Resists cutting, but cold flows
6. Abrasion resistance	Fair	Good
C. Electrical Characteristics		
1. Fundamental properties		
Volume resistivity (ohm-cm)	10^{15} - 10^{16}	10^{18}
Dielectric Strength (volts/mil)	425 - 500	750
Dielectric constant (60 cps)	3.0 - 3.5	2.0
Power factor (60 cps)	.0010 - .0050	.0003
2. Resistance to dielectric fatigue	Very good	Poor
3. Arc resistance	Very good	Very good
4. Corona resistance	Outstanding	Poor
D. Chemical Resistance		
1. General	Good	Outstanding
2. Resistance to moisture absorption	Good	Excellent
3. Ozone resistance	Excellent	Good
4. Radiation resistance	Good	Poor

DISCUSSION

I. Raw Material Properties

Silicone rubber includes a large family of compounds resulting from the incorporation of mineral fillers into a polyorganosiloxane gum. The chemical structure of the polymer is a silicon-oxygen backbone modified by organic side chains such as methyl, phenyl and vinyl. These compounds are classified as thermosetting because a vulcanizing operation is required to incorporate elastomeric properties. Subsequent applications of heat will not cause thermal softening or flow of the insulation from the conductor.

Teflon is a highly crystalline linear polymer composed of a carbon to carbon backbone with fluorine atoms attached. Although thermoplastic, it has excellent stability at high temperatures. The polymer has a very high melt viscosity, not becoming fluid at its melting point of 620F.

Silicone rubber and Teflon are both more expensive than common organic insulating materials. However, their better properties often makes their use practicable under operating conditions too severe for organic materials. Their superior performance frequently makes possible economies in design, installation, operation and maintenance, which more than compensate for their higher initial cost.

The raw material price of Teflon is more than double that of silicone rubber compounds most commonly used for wire insulation, and Teflon's significantly higher specific gravity spreads the cost differential even further. This is offset to some degree by the fact that Teflon is often used in thinner wall sections than silicone rubber. However, the cost of the processing techniques used for insulating wire with Teflon are inherently very much higher than those applicable to silicone rubber. For this reason, the cost of wire or cable insulated with Teflon is almost certain to be several times higher than those employing silicone rubber and designed to do the same job. A typical ratio of costs of completed cable is about five to one, and may sometimes reach ten to one.

II. Insulated Wire Properties

A. Installation and Handling

1. Lengths supplied

While progress has been made by certain individual wire fabricators toward the goal of supplying Teflon insulated wire in long continuous lengths, most fabricators use the ram extrusion process. This technique limits the quantity of wire that can be insulated in a continuous length.

Silicone rubber insulated wire is available in unlimited lengths.

2. Ease of stripping

Because of the inherent toughness of the insulation, Teflon coated wire is not easy to strip. It is difficult to regulate the cutting pliers to cut completely through the insulation without nicking the conductor, particularly with stranded conductors.

Silicone rubber does not have to be cut through completely for easy stripping, thus lessening the danger of conductor damage.

A. Installation and Handling (Cont'd)

3. Effect of right angle bends

One wire user has commented that breakage of Teflon insulation can occur when the wire is subjected to a sharp right angle bend during installation. Any flaws tend to be aggravated and crack propagation rate is very fast. Being truly elastomeric, silicone rubber does not display this weakness.

4. Crushing with pliers

Both materials can be damaged with pliers during installation unless reasonable care is used. While Teflon will stand more abuse, crushing of the insulation may result in breakage.

5. Flexibility

Silicone rubber insulated wire has excellent (true rubber) flexibility at room temperatures and maintains this flexibility at temperatures considerably below -100°F. For extreme low temperature service (below -65°F) CLASS 500 compounds, based on phenyl-containing silicone gums, should be specified.

Teflon is inherently a fairly stiff material. It reduces the flexibility of conductors and makes them more difficult to handle. A degree of flexibility is maintained at temperatures below -100°F.

6. Solderability

Unlike conventional low melting point thermoplastic materials, neither silicone rubber nor Teflon will melt nor shrink excessively during soldering operations. This feature is extremely important during wiring of complex control panels where the slip of a soldering iron may ruin adjacent installations.

7. Space factors

Available in wall thicknesses as thin as .008", Teflon is outstanding for thin-wall processing. The thinnest wall thickness currently specified for silicone rubber insulation is about .012". This is much thinner than formerly available and is due to improvements made in silicone rubber products and processability. Walls thinner than .012" have been processed and are available from some sources.

8. Conductor Plating

The selection of conductors for use with silicone rubber insulation is dictated by service conditions rather than being influenced by decomposition products of the insulation. Plated conductors must be used with Teflon to prevent conductor corrosion during processing or service.

B. Service Characteristics

1. Service temperature range

Both Teflon and silicone rubber perform well over the temperature range from -100 to +500°F.

(a) High temperature stability. The two materials have excellent high temperature stability. MIL-W-16878C specification covering high temperature hook-up wire rates both materials for service at 200°C (392°F). The two insulating materials will withstand months of continuous exposure at temperatures approaching 500°F.

Silicone rubber is approved by Underwriters' Laboratories for service at 200°C (392°F). With proper compound selection, long service life is possible at 500°F. Temperatures as high as 600°F can be withstood for short periods (100 or more hours). Equipment design will frequently permit use of silicone rubber insulated wire at still higher temperatures for short times.

Prolonged high temperature aging of silicone rubber results in a gradual hardening, shrinkage and ultimate embrittlement. Its decomposition products are of a non-toxic nature. See Figure I.

At elevated temperatures Teflon will decompose, giving off fluorine-containing materials. The rate of decomposition is reported to be insignificant below 750°F, but adequate ventilation to remove harmful vapors is recommended when Teflon is used in service at temperatures above 400°F[2].

(b) Low temperature flexibility. Silicone rubber insulated wire retains excellent flexibility and usefulness at temperatures well below -100°F. For extreme low temperature service (below -65°F) CLASS 500 compounds should be specified. Although inherently much stiffer material than silicone rubber, Teflon retains a usable degree of flexibility at temperatures below -100°F.

2. Overload reliability

Under high overload conditions (300 to 400%) conductors become extremely hot and cause decomposition of Teflon insulation, with evolution of toxic fumes. Under similar conditions silicone rubber may become brittle, but, if protected by an exterior glass braid, will retain insulating properties. At still higher overloads (above 400%) performance of silicone rubber will vary, dependent on the wire construction.

3. Flame resistance

Silicone rubber is slow-burning. Its ash is mainly silicon dioxide, a good dielectric. In extreme contrast to organic materials, the silicon dioxide ash retains about 90% of the original volume of the elastomer and, if held in place, continues to serve as insulation after fire damage occurs. Teflon is non-flammable but will decompose in a direct flame, giving off toxic fumes.

B. Service Characteristics (Cont'd)

4. Cold flow

One of Teflon's greatest drawbacks is its tendency to flow under pressure over a period of time at almost any temperature. This is due to its fundamentally plastic, rather than elastomeric, nature. Although some return does take place upon removal of the exerted force, much of the deformation is permanent. Silicone rubber, being truly elastomeric and exhibiting excellent compression set resistance over a wide temperature range, has far less tendency to cold flow.

5. Cut-through resistance

In the common (but questionably significant) "thumb nail" test, Teflon appears to be appreciably tougher than silicone rubber. However, the more newly-developed silicone rubber compounds are relatively good in this respect, in comparison with earlier stocks.

Of greater significance than the thumb nail test is the ability of wire insulation in actual service to withstand lacing when a number of conductors are tied into a harness. Teflon is not readily cut by tight laces, but its poor cold flow characteristics over a period of time make it virtually impossible to keep the lacing tight. Newer silicone rubber stocks, with better physical properties than early compounds, are tough enough to withstand lacing cut-through and will not promote loosening due to cold flow.

6. Abrasion resistance

While tests are admittedly inaccurate and difficult to correlate with application conditions, most abrasion tests indicate silicone rubber to be relatively poor in this respect. Newer technology has led to some improvements. Teflon has good abrasion resistance under relatively light loads and low rubbing velocities. Under more severe test conditions, performance is less satisfactory.

C. Electrical Characteristics

1. Fundamental properties

Teflon has outstanding electrical characteristics. Exceptional stability in dielectric constant and power factor make it particularly applicable for high frequency applications.

The electricals of silicone rubber will vary with the composition. Electrical grade compounds are very good in the four fundamental properties of volume resistivity, dielectric strength, dielectric constant and power factor. Most application requirements can be met without difficulty.

2. Dielectric fatigue

Short-time dielectric strength values for Teflon are higher than values for silicone rubber. However, Teflon will erode and exhibit dielectric fatigue when exposed for longer periods of time at moderate electric stress. Silicone rubber is far less apt to display this characteristic. See Figure II.

C. Electrical Characteristics (Cont'd)

3. Arc Resistance

Both silicone rubber and Teflon have good arc resistance and will withstand standard tests for periods of time in excess of 200 seconds. No carbon path is formed regardless of temperature.

4. Corona Resistance

Silicone rubber's resistance to corona is outstanding among all elastomers, approaching that of mica(3). Teflon, like other organic materials, is eroded by corona and special designs are required to minimize corona at high voltages.

D. Chemical Resistance

1. General

Probably the most outstanding property of Teflon is its resistance to attack by practically all commonly used chemicals and solvents.

Silicone rubber has good resistance to many oils, solvents and other chemicals. Certain solvents, such as aromatic hydrocarbons and aviation gasoline, may cause excessive swelling of silicone rubber. However, the loss of physical properties is frequently temporary, with original properties being restored when the solvent evaporates. Application of braids or other protective coatings improves the solvent resistance of silicone rubber insulated wire.

2. Moisture Absorption

Teflon does not absorb moisture. Silicone rubber compounds vary in this respect with the type of filler used in the formulation. The better compounds will absorb very little - less than 10 milligrams of water per square inch of surface under the standard ASTM water immersion test for 7 days at 70°C (158°F).

3. Ozone Resistance

Teflon is not appreciably affected by ozone.

Silicone rubber has exceptional resistance to ozone atmospheres, being virtually unaffected by concentrations as high as 500 parts per million after hundreds of hours of exposure.

4. Radiation Resistance

Silicone rubber's resistance to radiation ranks with the best of the heat resistant elastomers(7) and is clearly superior to that of Teflon. Properly compounded, silicone rubber will resist a gamma ray dosage of 1×10^8 roentgens. In contrast, Teflon is severely damaged by a concentration of 5×10^6 roentgens and becomes extremely brittle and crumbly.

CONCLUSION

The selection of the proper insulation material for a given application must be influenced by a combination of the economic factors and service conditions involved. Silicone rubber and Teflon each has areas of relative superiority. There are other areas in which equivalent properties are demonstrated - in such cases, silicone's lower cost will often provide the choice. The design engineer must decide which areas possess the most significance for each specific application.

One approach that may well be considered is using both materials in a single construction. Wire designs using silicone rubber insulation and a Teflon jacket have been made. Theoretically, this technique should offer the strong points of each material and eliminate many of the less desirable characteristics. This construction, or others of similar nature, may be useful in meeting particularly difficult service requirements.

Silicone rubber and Teflon are both relatively new materials and the technology of each is advancing rapidly. The design engineer can best get the benefit of the newest technology coupled with practical experience by working closely with a competent wire fabricator. Additional assistance as well as the latest technical information on silicone rubber is available from the General Electric Company, Silicone Products Department, Waterford, New York.

BIBLIOGRAPHY

1. DuPont Teflon Tetrafluoroethylene Resin, E. I du Pont de Nemours & Company, Polychemicals Department, 1955.
2. Designing with Teflon, Machine Design, September 5 and 19, October 3 and 17, 1957.
3. Corona Resistance of Silicone Rubber, S. I. Reynolds, Research Laboratory, General Electric Company, Report No. RL-659, February 1952.
4. New Developments in Silicone Rubber Compounds for Extruded Electrical Insulation, M. G. Noble, Wire and Wire Products, February 1957.
5. New Trends in High Temperature Cables, B. J Mulvey, General Electric Review, March 1957.
6. Military Specification MIL-W-16878 (NAVY): Wire, Electrical (Insulated, High Temperature), 19 August 1955.
7. Effect of Gamma Radiation on Heat-Resistant Elastomers, Robert Harrington, Hanford Laboratories, General Electric Company, Rubber Age, December 1957.

Figure I - Effect of 400°F heat aging on silicone rubber

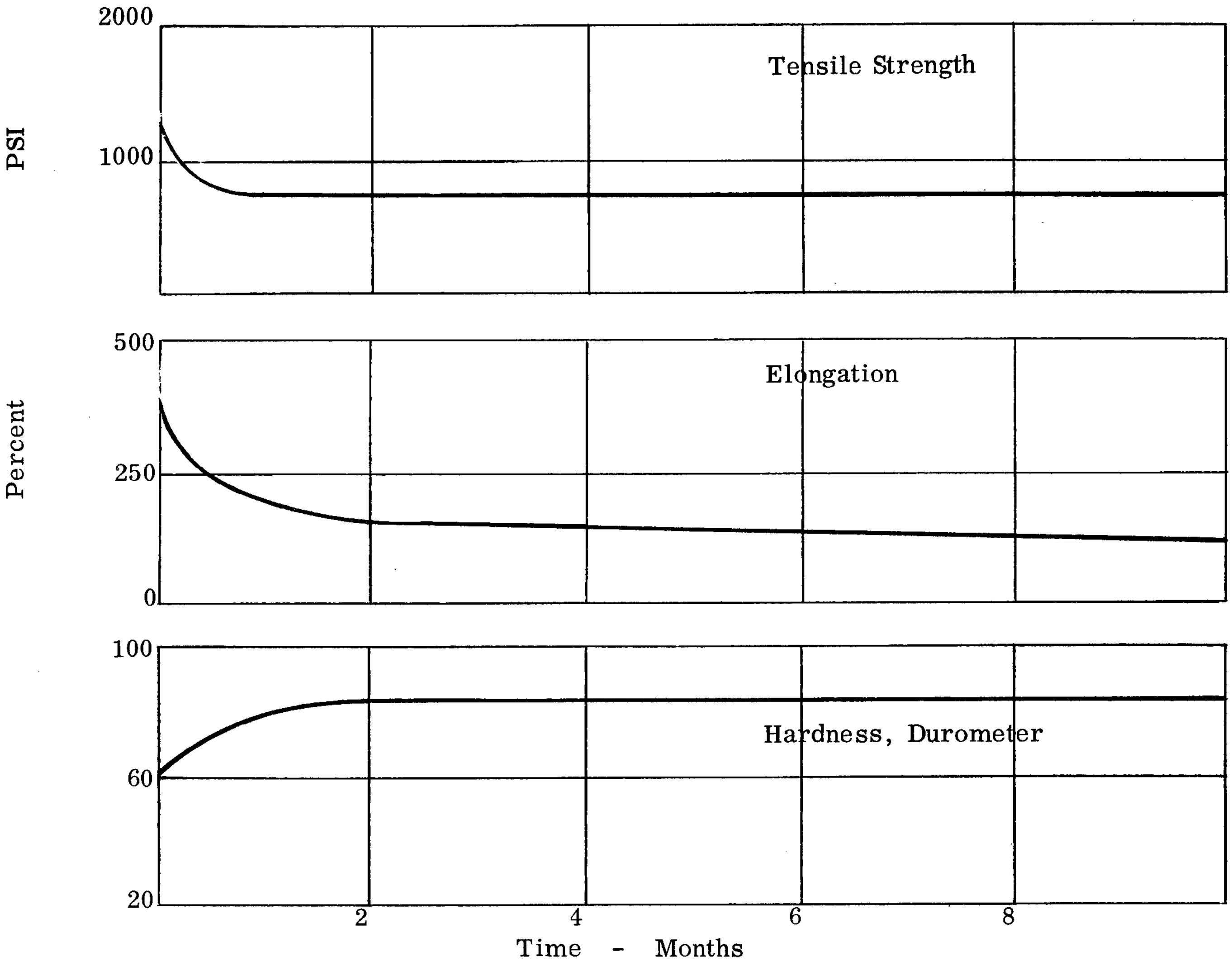
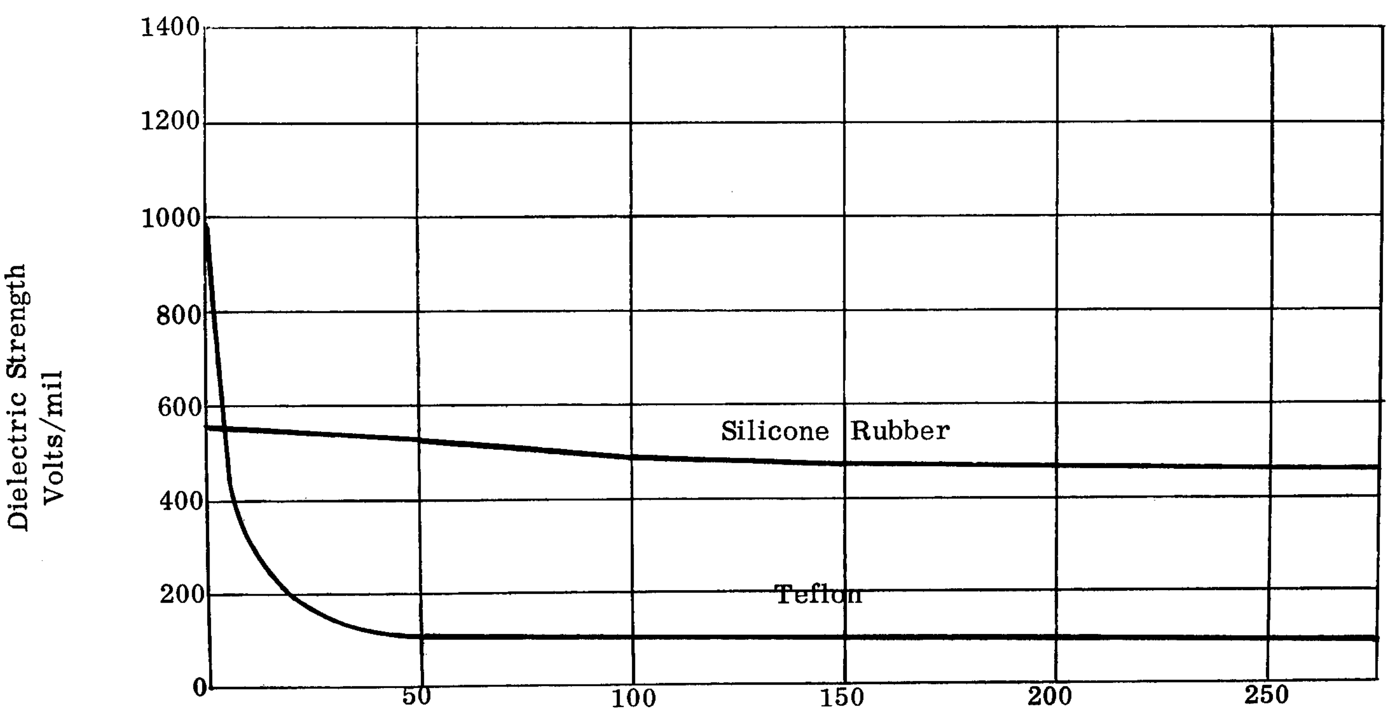


Figure II - DIELECTRIC FATIGUE
Measured on 50-mil sheets



WORK SHEET

PLASTEC

PLASTEC NUMBER 2112

ACCESSION NO. B

INDEX TERMS: (LIST BELOW)

	Pages
Insulation – Electrical	2
silicone rubber	2
teflon	2
~~physical properties~~	~~PA~~
Electrical properties - Silicone rubber	PA
Chemical resistance - Silicone rubber	PA
Noble, M. G.	TP
Flame resistance - Silicone rubber	7
Abrasion resistance - Silicone rubber	8